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Experimental Study on Stabilization of Expansive Clay Using Polypropylene-Based Reinforcement and Copper Slag Admixture

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Abstract

Expansive black cotton soils exhibit substantial volume change with moisture variation and often require stabilization before use as pavement subgrade. This study examines the individual and combined effects of copper slag (CS) and polypropylene (PP) fibre on compaction, unconfined compressive strength (UCS) and California Bearing Ratio (CBR). CS was investigated at 6–24% of dry soil mass, PP fibre at 0.5–2.0%, and combined mixtures at CS contents of 3–12% with corresponding PP contents of 0.5–2.0%. The reported UCS reached 1.722 kg/cm² at 6% CS and 0.944 kg/cm² at 0.5% PP fibre. The maximum unsoaked CBR values in the individual series were 4.89% for 6% CS and 5.80% for 0.5% PP fibre. For combined mixtures, the highest unsoaked CBR was 5.81% at 6% CS + 1% PP, while the corresponding soaked CBR was 1.93%. The combined mixtures did not demonstrate a consistent UCS advantage over individual stabilizers. Important inconsistencies occur in compaction values, units, mix nomenclature and test reporting; several planned swelling tests have no numerical results. Findings are therefore treated as preliminary laboratory observations, not a validated optimum design.

Keywords—Expansive clay, black cotton soil, copper slag, polypropylene fibre, soil stabilization, UCS, California Bearing Ratio.

I. INTRODUCTION

Expansive soils undergo significant swelling during wetting and shrinkage during drying. Repeated volume changes can induce differential movement, cracking and premature pavement distress. Black cotton soil is a problematic subgrade material in many regions of India. Stabilization using industrial by-products and discrete reinforcement offers a potential method of improving engineering performance while reducing dependence on conventional borrow materials.

Copper slag is a granular by-product of copper smelting. Its relatively high specific gravity and granular texture may modify soil gradation, packing and frictional resistance. Polypropylene fibres act as distributed tensile inclusions that may restrain local deformation and crack propagation. Prior studies have investigated PP fibre and copper slag treatment of expansive soils [2], [6]–[10].

A. Objectives and Scope

This study evaluates the index properties of black cotton soil; changes in maximum dry density (MDD) and optimum moisture content (OMC); UCS and CBR of individually treated soils; and soaked/unsoaked CBR of selected combined mixtures. Although free swell index and swelling pressure are listed in the intended programme, numerical results for these tests are absent from the results chapter.

II. MATERIALS AND EXPERIMENTAL PROGRAMME

The base material was black cotton soil. Table I summarizes its reported properties. Liquid limit of 90.27%, plastic limit of 47.7% and plasticity index of 42.5% indicate highly plastic soil. Baseline MDD was reported as 1.60 g/cc and OMC as approximately 23.5%.

TABLE I. BASIC PROPERTIES OF BLACK COTTON SOIL

Property	Reported value
Specific gravity	2.42
Liquid limit	90.27%
Plastic limit	47.7%
Plasticity index	42.5%
Shrinkage limit	18.12%
OMC	23.52% (Table 3.1); 23.5% (Table 4.1)
MDD	1.60 g/cc
CBR	2.58% soaked; 3.22% unsoaked
UCS	0.775 kg/cm² (reported)

PP reinforcement was described as monofilament/fibrillated fibre, commonly 12 mm long and 0.03–0.05 mm in diameter, with specific gravity 0.90–0.91 and tensile strength 300–700 MPa. Copper slag was described as angular and rough, with specific gravity 3.4–3.8 and particle size 0.075–4.75 mm.

TABLE II. MATERIAL CHARACTERISTICS

Material	Property	Reported value
PP fibre	Length; diameter	6–12 mm; 0.03–0.05 mm
PP fibre	Specific gravity	0.90–0.91
PP fibre	Tensile strength	300–700 MPa
Copper slag	Specific gravity	3.4–3.8
Copper slag	Particle size	0.075–4.75 mm
Copper slag	Bulk density	1.8–2.1 g/cm³

Individual CS contents were 6, 12, 18 and 24% of dry soil mass; PP fibre contents were 0.5, 1.0, 1.5 and 2.0%. Combined mixtures comprised 3% CS + 0.5% PP, 6% CS + 1% PP, 9% CS + 1.5% PP and 12% CS + 2% PP. The methodology proposes wider dosage ranges than those represented in the results tables. Standard Proctor, UCS and CBR procedures are described, but curing duration, replication and all conditioning details are not consistently reported.

III. RESULTS AND DISCUSSION

A. Compaction Characteristics

In the copper-slag series, reported MDD increased to 2.00 g/cc at 24% CS, with OMC of 30%. Intermediate values are non-monotonic: 6% CS is associated with MDD 1.50 g/cc and OMC 12.5%, followed by 1.56 g/cc and 24% at 12% CS. These abrupt changes require verification against original Proctor curves and moisture calculations.

TABLE III. COMPACTION RESULTS FOR COPPER-SLAG-TREATED SOIL

CS (%)	MDD (g/cc)	OMC (%)
0	1.6	23.5
6	1.5	12.5
12	1.56	24
18	1.75	16.5
24	2.0	30

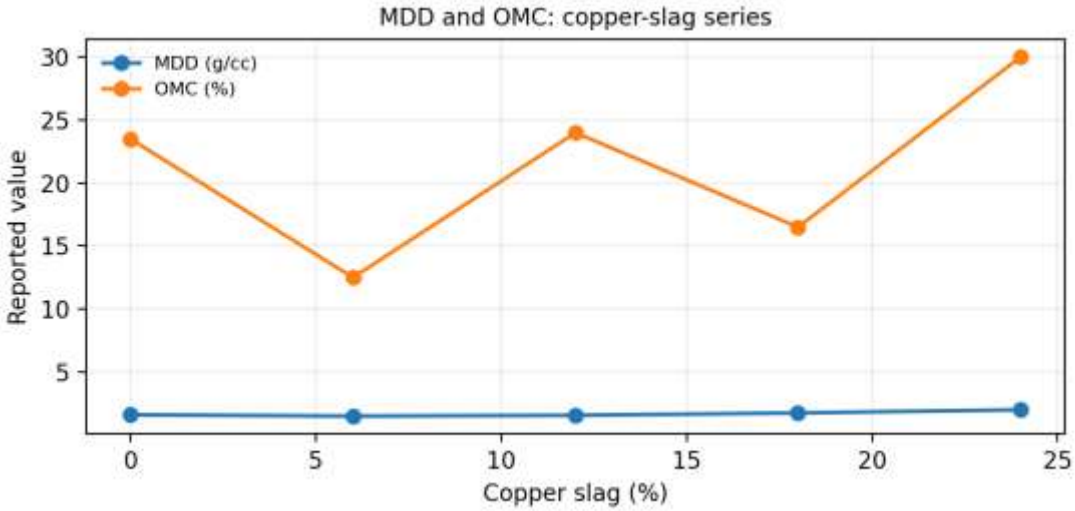


Fig. 1. Reported MDD and OMC for copper-slag-treated soil

For PP fibre, MDD decreased from 1.60 g/cc at 0.5% fibre to 1.35 g/cc at 1.5%, then increased slightly to 1.43 g/cc at 2%. OMC varied between 23 and 31%, without a monotonic trend.

TABLE IV. COMPACTION RESULTS FOR PP-FIBRE-REINFORCED SOIL

PP (%)	MDD (g/cc)	OMC (%)
0.5	1.6	30
1	1.36	23
1.5	1.35	29
2	1.43	31

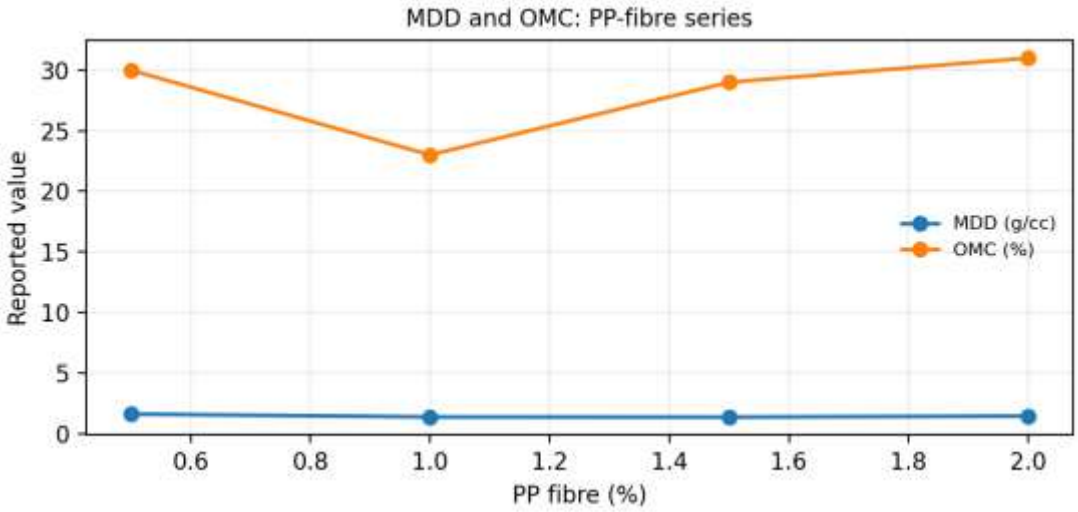


Fig. 2. Reported MDD and OMC for PP-fibre-reinforced soil

TABLE V. COMPACTION RESULTS FOR COMBINED CS–PP MIXTURES

CS (%) + PP (%)	MDD (g/cc)	OMC (%)
3 + 0.5	1.65	30
6 + 1.0	1.49	31
9 + 1.5	1.51	29
12 + 2.0	1.5	27

The combined series has MDD values of 1.49–1.65 g/cc and OMC values of 27–31%. The maximum MDD occurs at the lowest combined dosage. The reported values do not show a systematic increase in MDD with increasing copper slag.

B. Unconfined Compressive Strength

The CS series recorded its highest reported UCS of 1.722 kg/cm² at 6% CS, followed by a marked reduction at 12–24%. The PP series recorded 0.944 kg/cm² at 0.5% fibre, decreasing at higher dosages. The combined series declined from 0.626 kg/cm² at 3% CS + 0.5% PP to 0.235 kg/cm² at 12% CS + 2% PP.

TABLE VI. REPORTED UCS OF STABILIZED BLACK COTTON SOIL

Treatment	UCS (kg/cm²)
6% CS	1.722
12% CS	0.685
18% CS	0.712
24% CS	0.500
0.5% PP	0.944
1.0% PP	0.782
1.5% PP	0.665
2.0% PP	0.538
3% CS + 0.5% PP	0.626
6% CS + 1% PP	0.602
9% CS + 1.5% PP	0.550
12% CS + 2% PP	0.235

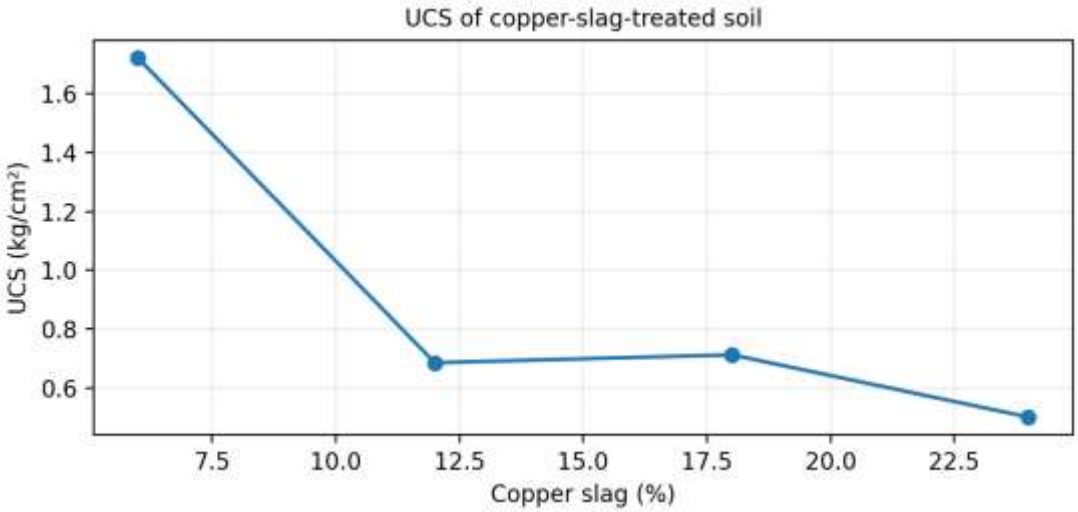


Fig. 3. UCS variation with copper-slag content.

The individual-treatment data suggest that lower additive contents performed better within the tested ranges. However, the untreated UCS is separately stated as 0.775 kg/cm², while a matching control is not consistently included in Chapter 4 tables. Reliable percentage improvements therefore cannot be calculated for all mixtures. The source labels the UCS results as 0-day curing but does not fully define conditioning and elapsed time.

C. California Bearing Ratio

Unsoaked CBR values for the CS series ranged from 3.22 to 4.89%, with the maximum at 6% CS. The PP series ranged from 3.20 to 5.80%, with the maximum at 0.5% fibre. In the combined series, the highest unsoaked CBR was 5.81% at 6% CS + 1% PP. The corresponding soaked CBR was 1.93%.

TABLE VII. UN-SOAKED CBR FOR INDIVIDUAL STABILIZER SERIES

Treatment	CBR (%)
6% CS	4.89
12% CS	3.87
18% CS	4.5
24% CS	3.22
0.5% PP	5.8
1.0% PP	3.87
1.5% PP	3.22
2.0% PP	3.2

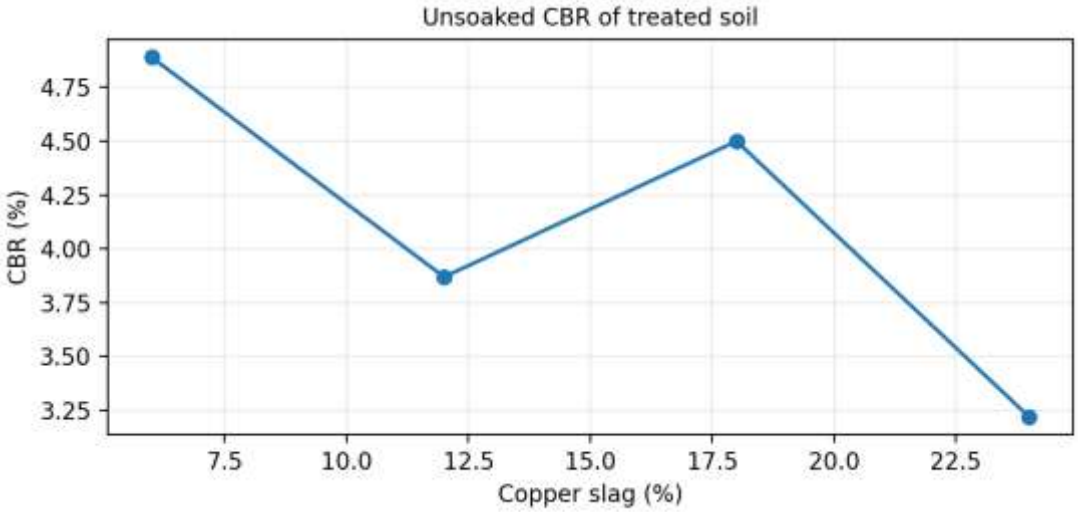


Fig. 4. Unsoaked CBR variation with copper-slag content.

TABLE VIII. SOAKED AND UNSOAKED CBR FOR COMBINED MIXTURES

CS (%) + PP (%)	Unsoaked (%)	Soaked (%)
3 + 0.5	5.16	2.58
6 + 1.0	5.81	1.93
9 + 1.5	4.51	2.15
12 + 2.0	3.87	1.93

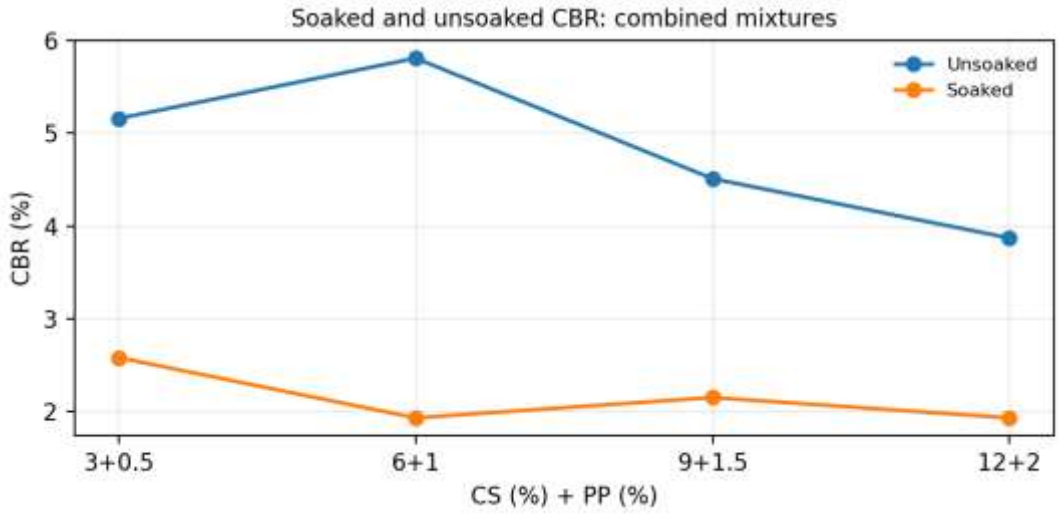


Fig. 5. Soaked and unsoaked CBR for combined CS–PP mixtures.

For 6% CS + 1% PP, CBR fell from 5.81% unsoaked to 1.93% soaked, a reduction of approximately 66.8%. The 3% CS + 0.5% PP mixture recorded the highest soaked CBR (2.58%). This demonstrates the importance of soaked performance when assessing expansive soil for pavement subgrade. Soaked CBR results for the individual CS-only and PP-only series are not supplied, preventing a complete comparison.

IV. ENGINEERING INTERPRETATION

Copper slag may contribute a granular skeleton and frictional resistance, while PP fibres may mobilize tensile resistance through soil–fibre interaction. At higher fibre contents, inadequate dispersion or clustering can reduce uniformity. These are plausible mechanisms consistent with prior studies [2], [5], [7], [8], but the report does not provide microscopy, pull-out measurements or repeatability statistics to verify them. The combined UCS values are below the separate peak values of the individual stabilizers, and hence do not establish a synergistic strength benefit. Combined CBR is more favourable in the unsoaked condition, but soaked performance remains low.

V. CONCLUSIONS

1. The maximum reported UCS in the CS series was 1.722 kg/cm² at 6% CS; the PP series maximum was 0.944 kg/cm² at 0.5% fibre.
2. Maximum unsoaked CBR values in individual series were 4.89% at 6% CS and 5.80% at 0.5% PP fibre.
3. For combined mixtures, 6% CS + 1% PP produced the highest unsoaked CBR (5.81%), while 3% CS + 0.5% PP produced the highest soaked CBR (2.58%).
4. Soaking reduced the combined-mixture CBR substantially; for 6% CS + 1% PP it decreased from 5.81% to 1.93%.
5. Combined UCS values declined as paired additive contents increased and did not establish a synergistic benefit over the individual-treatment maxima.
6. Compaction values require verification. Further replicated testing, complete soaked CBR comparisons, swelling tests, leaching assessment and field validation are necessary before recommending a subgrade mix.

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